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Application No. 10/528,650
Attorney's Docket No. 000008-004

In re Patent Application of

Peter GROCHE et al.

Application No. 10/528,650

Filed: March 21, 2005

For: PROFILED GUIDING ELEMENT

Group Art Unit: 3656

Examiner: Pilkington, James

Conf. No.: 7130

DECLARATION OF PETER GROCHE

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, Peter Groche, declare as follows:

1. I am an inventor of the subject matter claimed in U.S. Patent Application No. 10/528,650 ("the '650 application").

2. DE 2 431 935 ("Jelenak") describes a method based on the determination that bearings should be made from a very hard material that cannot be easily deformed. Otherwise the bearings must be hardened in additional processes subsequent to manufacture of said bearings, resulting in an increase of production time and costs. This is supported by, for example, the following:

a. Jelenak's references to the problems of the prior art (p.1, lines 10 ff.: "Nachteilig ist hierbei aber, daß hohe Umformungsgrade unvermeidbar sind und daß dadurch das Verfahren auf gut umformbare Werkstoffe begrenzt ist" - Translation: "It is a disadvantage [of a method according to prior art] that high deformation is unavoidable and that therefore application of said method is limited to good deformable materials");

b. Jelenak's description of the problem to be solved (p. 2 lines 23 and 23: "... es soll auch nur schlecht umformbares Material verwendbar sein." - Translation: "[The method according to the present invention of Jelenak] shall be applicable to hardly deformable materials."); and

c. Statements in the disclosure of the alleged invention (p. 4, lines 19 ff.: "Durch die geringe Umformung während der Fertigung ist auch die Fertigung aus schwer umformbaren Materialien wie z.B. Messing oder nichtrostendem Stahl möglich. Durch die geringe Umformung ergibt sich weiterhin ebenfalls eine geringe Umformzeit, welche die Wirtschaftlichkeit des Verfahrens stark erhöht" - Translation: "Due to the reduced forming during the production it is also possible to apply said production to hardly deformable materials like e.g. brass or stainless steel. The reduced forming furthermore results in short process duration, which enhances the economic efficiency.")

3. In summary, Jelenak teaches a method that includes a first splitting step and a subsequent profiling step. Only very hard materials are suitable for splitting. For soft and easily deformable materials an uncontrollable deformation would occur around the splitting roll.

4. A split and profiled structure made according to the method described in Jelenak will usually show some remnant of the split remaining, resulting in reduced durability of flanges.

5. The method of forming referred to as "profiling gaps" in the '650 application is described in greater detail in my German Offenlegungsschrift DE10039768A1 and my article, attached as Appendix A, entitled "Basics of linear flow splitting". Even though the forming method is referred to as "linear flow splitting" in the article, it is not a splitting process but, rather, is a deformation process and is referred to herein as the "profiling gaps" method. . Attached Appendix B illustrates differences between the profiling gaps method and the method

described by Jelenak. A flanged article produced by the profiling gaps method has a different structure than a flanged article produced according to the method described in Jelenak. A flanged article produced by the profiling gaps method will not, for example, have a remnant of a split as is typical with a flanged article made according to the method described in Jelenak.

6. The profiling gaps method requires good deformable materials. The plain sheet metal is not split, i.e., cut and divided in two halves, but deformed by a cold forming process. By use of said method of profiling gaps the resulting flanges show increased stiffness and hardness and are able to resist higher loads as would be expected by use of good deformable material. Contrary to expectations, through the use of good deformable material, the method of the present invention allows for easy and low cost manufacture of bearings with high surface quality and sufficient hardness for all practical purposes. Therefore it is not mandatory or necessary to make use of very hard raw material that is difficult to process and results in costly manufacture of bearings and alike.

7. Persons skilled in the art would not modify the method described by Jelenak in view of the profiling gaps method described in, e.g., my DE10039768, (or modify the profiling gaps method in view of the method described by Jelenak) because they are intended to be used with completely different materials (hard material for Jelenak versus good deformable material for Groche). Jelenak cannot process good deformable materials and the profiling gaps method requires such material. The need for use of a hard material as with Jelenak is avoided in the profiling gaps method.

8. Even though both disclosures show similar features of tools and rolling bodies used for manufacture of profiled elements, there is no splitting tool used in a profiling gaps method and there is no forming subsequent to dividing a sheet metal into two halves. For

Jelenak a splitting tool is mandatory, whereas the present invention deforms the sheet metal without producing cut surfaces.

9. Yet another difference between the method described in Jelenak and the profiling gaps method is that, in Jelenak, the thickness of flanges must equal the thickness of the original sheet metal. By contrast, the thickness of the flanges produced by the profiling gaps method can be varied and might differ.

I hereby state that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.

Date: 7/10, 2009

By: [signature]
Peter Groche

APPENDIX A

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Basics of linear flow splitting

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Abstract

Linear flow splitting enables the forming of bifurcated profiles in integral style out of sheet metal without joining, lamination of material or heating of the semi-finished part. The new roll forming process uses obtuse angled splitting rolls and supporting rolls to increase the surface of the band edge. The high hydrostatic compressive stresses induced in the local forming zone during the process lead to an increased formability of the material and enable the realization of large strains. Produced parts are characterized by increased stiffness, high surface hardness and low surface roughness. The basic principle of the process and the occurring phenomena are described in this paper.

Keywords: Sheet metal; Roll forming; Profile; Linear flow splitting

1. Introduction

In nature, an abundance of applications for the principle of bifurcation can be found. This spectrum ranges from aspects of lightweight design as seen, for instance, in wood and bone structures as well as the design of plant stalks to the influence of flows. Often several functions are realized simultaneously, illustrated by the cross-section of a horsetail plant (Fig. 1, right). The branched structure serves to ensure the requirements of static and stability in the stalk construction using as little material as possible [1].

Branched structures are used in technology as well. Examples from the field of lightweight design are half-timbering, box strap, sandwich and stringer constructions or different profile rows (Fig. 1, left) [2]. The use of bifurcations offers here the opportunity for efficient structural lightweight design, which aims for optimal progression of forces with minimal volume effort [3]. Mass reduction is usually useful or necessary in order to reach required system functions, e.g. high accelerations. Roll forming and bending procedures are state-of-the-art illustrations of bifurcated profiles, which were produced out of sheet metal by cold forming. The realization of sufficient stiffness often requires the integration of additional join patches with a local material lamination [4]. These yields to problems originating from discontinuous stiffness and residual stresses in the area of join patches. Process safety and quality control of the joining technologies employed depict another problem area, so that the goal productivity in serial production can often not be reached. Material separations in the sheet plane can be generated by means of conventional splitting processes in the area of rotation-symmetrical components, applying acute-angled rolls. Splitting with cold forming processes leads to characteristic tensile stresses in the fissure which end up in preliminary cracks. In operational life cycle this can lead to a fabrication-based failure of the work piece [5].

2. Principle of linear flow splitting

Linear flow splitting is a new massive forming process for the production of bifurcated profiles in integral style. The semi-finished part is a plane sheet metal which is transformed at ambient temperature by a specific tooling system, consisting of obtuse-angled splitting rolls and supporting rolls. The fixed tool system forms the work piece in discrete steps up to a profile with the final geometry.

The bifurcations originate from a surface enlargement of the sheet metal's band edge during material forming.

The bifurcated profile is marked by a web and two flanges. The surface beneath the splitting roll is defined as the upper side (Fig. 2).

According to the DIN 8580 et sqq. classification linear flow splitting is to be assigned to the forming procedures using compressive stresses. A final classification is suitable in the class

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Fig. 1. Stringer construction (left) and cross section of horsetail plants (right).

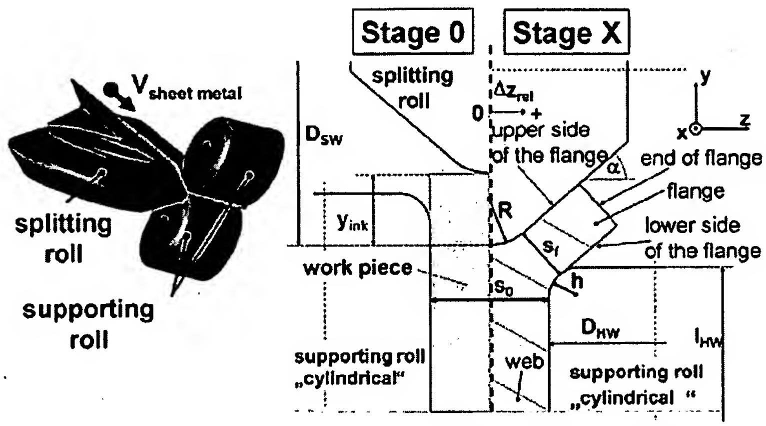


Fig. 2. Process principle (left) and geometrical characteristics of linear flow splitting (right).

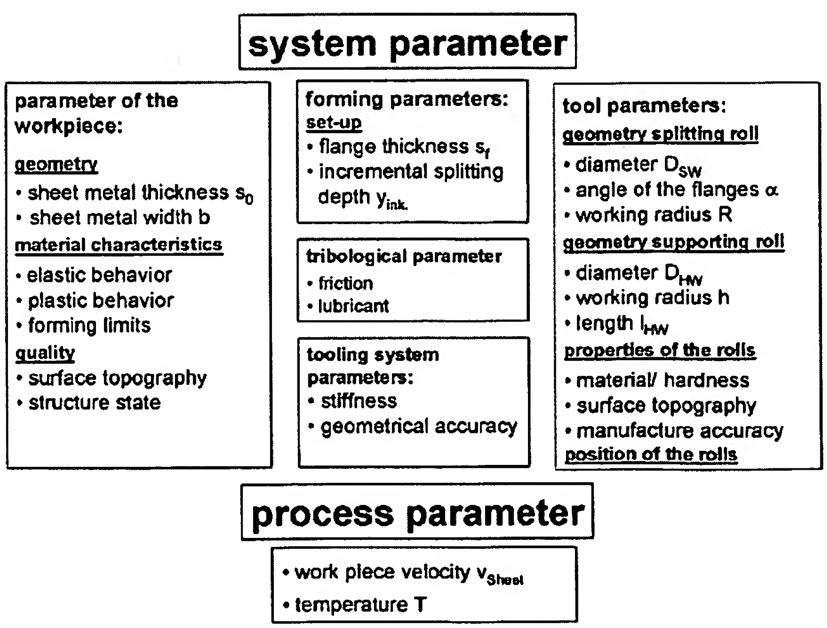


Fig. 3. Parameters of linear flow splitting.

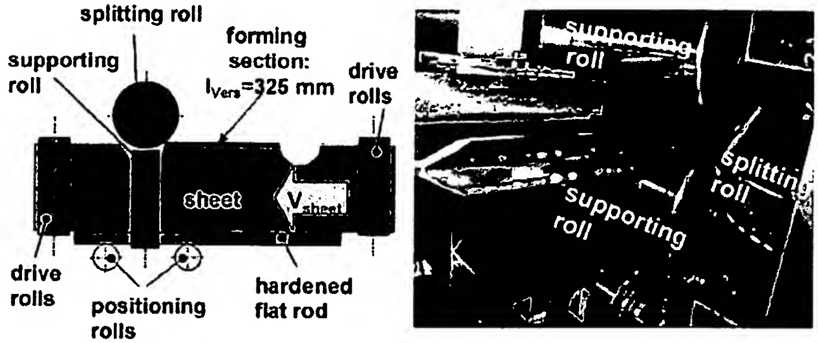


Fig. 4. Experimental concept draft (left) and tool system of linear flow splitting (right) [8].

"lengthwise roll forming of full bodies" [6]. The factors influencing linear flow splitting are arranged into system and process parameters in Fig. 3.

3. Tool system and experimental work

The experimental investigations were carried out in a reversing process on a roll forming device (Fig. 4).

The semi-finished part is a sheet metal which comprises two recesses. The forming section with the length $l_{Vers} = 325$ mm is in between, where forming takes place. The tool system is positioned towards the middle of the sheet metal in the area of the first recess, around the incremental splitting depth y_{ink}. Then, drive rolls placed in a conventional rack of the roll forming device initiate the feed of the sheet metal. The splitting proceeds. As soon as the rolls are in the area of the second recess, the feed of the sheet metal is stopped. The procedure described is repeated until attainment of the final splitting depth y_{ges}. Before each forming step, the contact-mating-splitting roll sheet metal is smeared with high-pressure grease. In order to measure the reaction forces at the splitting roll, the axis is used as a strain gage bolt. The measurement of the supporting rolls' reaction force is carried out via strain gage rings positioned behind the supporting bearing.

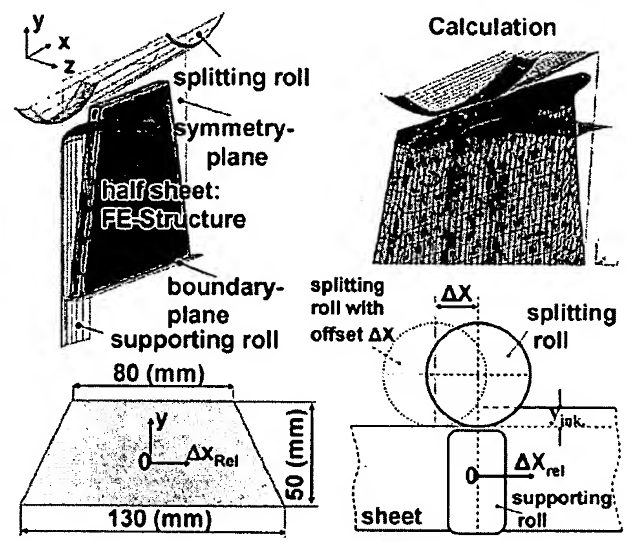


Fig. 5. Numerical model of the linear flow splitting process (above) and geometrical dimensions of the calculated work piece and schematic representation (top view; beneath).

4. Numerical investigations

The numerical process analyses are carried out with the FE-program system MSC Superform2002. This program distinguishes itself through an implicit equation solution and quasi-static calculation possibilities. The model (Fig. 5) contains the following idealizations:

- Friction-free contact between work piece and rolls.
- No consideration of thermal effects.
- Isotropic material attributes of the finite elements.

The geometries and kinematics of the rolls during the calculation are identical to the experimental work. Fig. 5 shows the geometrical dimensions of the modeled work piece and one calculated result. The splitting roll and supporting roll were shown in the position $\Delta x_{rel} = 0$ mm central to the calculated sheet metal (cp. Fig. 5 beneath). The forming zones are quan-

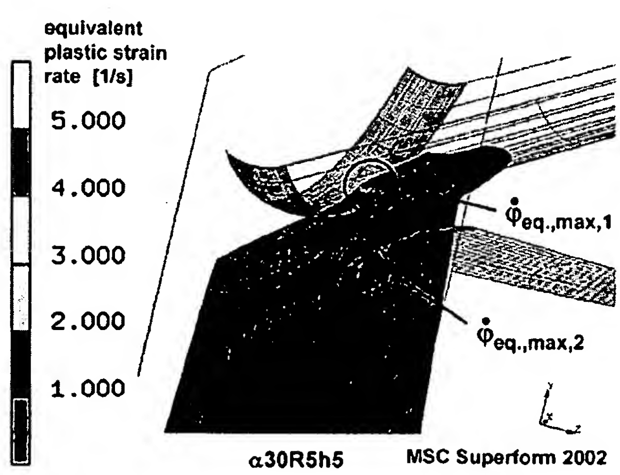


Fig. 6. Calculation of the equivalent plastic strain rate ($\alpha = 30°$; $R = 5$ mm; $h = 5$ mm; $s_0 = 6$ mm; $s_f = 3$ mm, $y_{ink} = 1$ mm, $y_{ges} = 10$ mm, DD11).

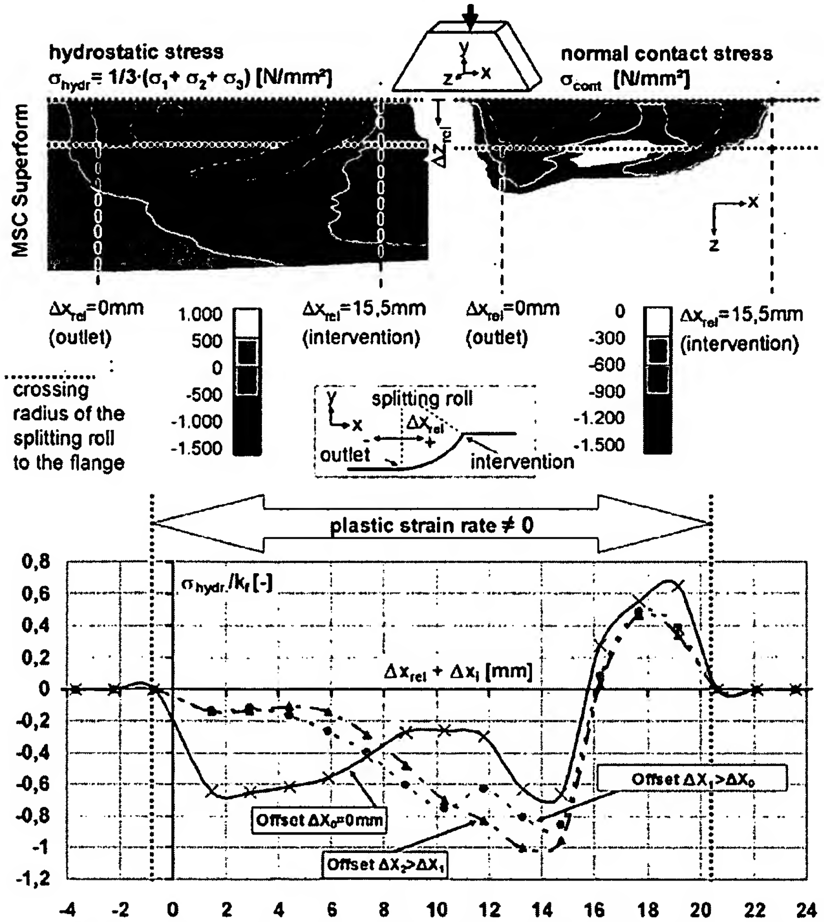


Fig. 7. Hydrostatic compressive stress and contact stress on the work piece surface and the influence of the splitting roll position at $\Delta z = 0$ (below) (configuration same as in Fig. 6).

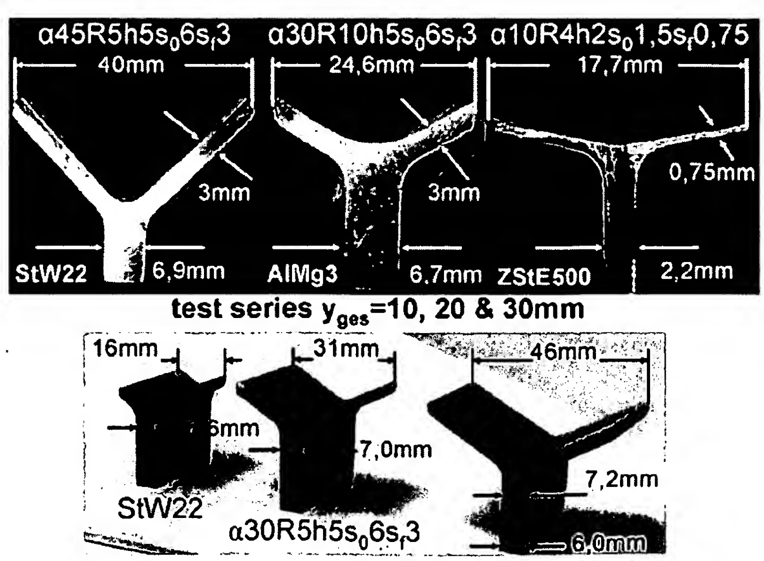


Fig. 8. Bifurcated profiles manufactured using DD11 (STW22), AlMg3 and H480LA (ZStE500).

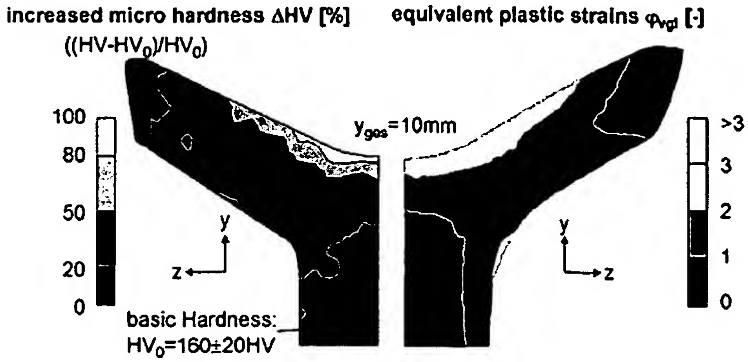


Fig. 9. Micro hardness and equivalent plastic strains of y_{ges} = 10 mm [8].

tifiable by the equivalent plastic strain rate $d\varphi_{eq.}/dt$ (Fig. 6). On the contact side of the splitting roll, large deformation gradients are noticeable, just behind the tool intervention. The maximum value $d\varphi_{eq.}/dt_{,max,1}$ is reached shortly behind and is located in the area of the symmetry plane. In the direction of the outlet area, the equivalent plastic strain rate reaches smaller values. After ending of the splitting roll contact, $d\varphi_{eq.}/dt$ becomes zero. On the side of the supporting rolls, the equivalent plastic strain rate is at its maximum $d\varphi_{eq.}/dt_{,max,2}$ in the radius contact area. With the speed relations being predominant in these places, two essential forming steps of the linear flow splitting can be determined. After the splitting roll intervention, the material is compressed in the direction of positive z- and negative y-axis. In contrast, only few changes of the equivalent plastic strain rate or pure rigid body movements of the material take place in the flange area. In the contact zone of the supporting roll radius, high velocity components are identifiable in positive y- and negative z-direction. This occurrence corresponds to a backward compression of the material. The contour cross section of bifurcated profiles is determined after the rolls have passed.

A qualitative correlation is noticeable during a comparison of the hydrostatic compressive stress σ_{hydr} and the contact stress σ_{cont} with the example of the DD11 material (Fig. 7). In areas of large surface pressure, high hydrostatic compressive stresses are present. In each case, maxima arise briefly behind the splitting roll intervention directly near the symmetry plane in places with maximum equivalent plastic strain rates. From there, minor stress values proceed and run out towards the contact area of the splitting roll flank. Before tool intervention, the σ_{hydr} values are positive. Furthermore, the priority contact is limited to a restricted area in the direction of the z-axis (0 mm < Δz_{rel} < 5 mm).

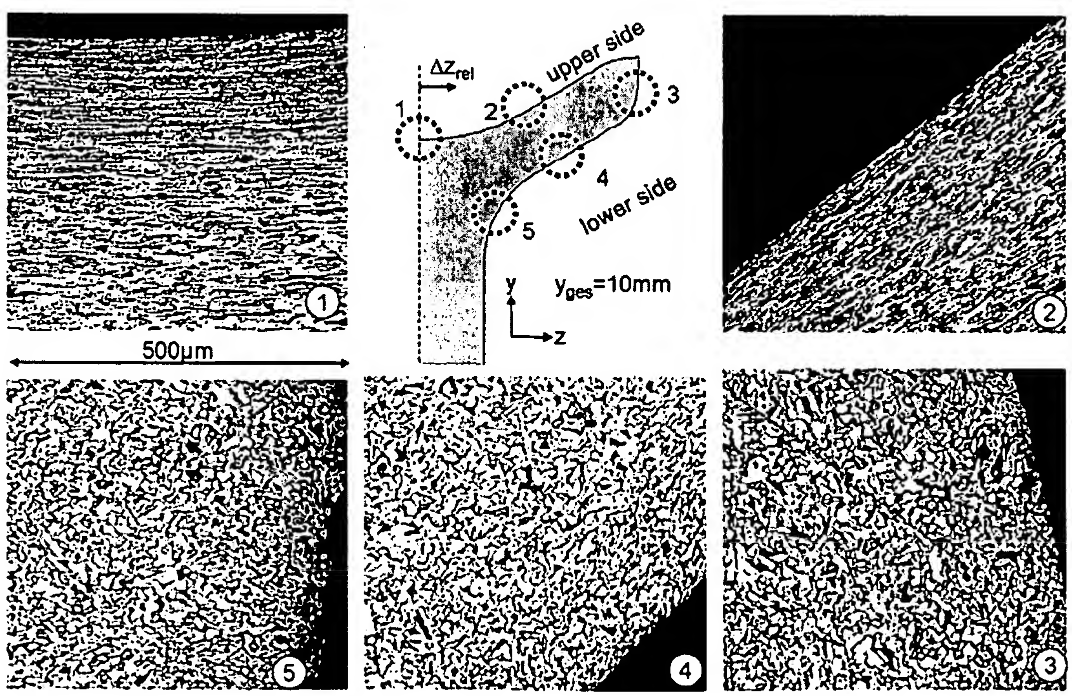


Fig. 10. Metallographic micrographs of well-chosen work piece zones (DD11) [8].

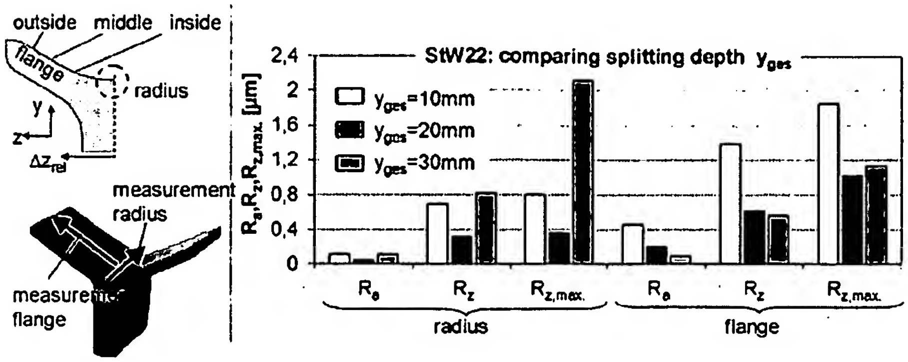


Fig. 11. Comparison of standardized surface roughness values in defined surface areas of the profile upper sides ($\alpha = 30$; $R = 5$; $h = 5$; $s_0 = 6$; $s_f = 3$; $y_{int} = 1$ mm).

Fig. 7 (below) shows the quotient σ_{hydr}/k_f, (k_f≙yield stress) for different splitting roll positions Δx in the area of $\Delta z = 0$ along the forming zone. To increase the formability of the material used, the portion of negative hydrostatic compressive stress σ_{hydr} has to rise [7]. The maximum portion of negative hydrostatic compressive stress σ_{hydr} occurs at an offset of Δx_2.

5. Component properties

The first series of experiments confirm that linear flow splitting is realizable without failure of the work pieces. Fig. 8 illustrates the typical characteristics of different test bodies. In example DD11, flanges just run out of the rolls' radii area. The differences in flange outlet angle and splitting roll angle ($\alpha = 30°$) move in a tolerance band of ±1°. The desired flange thickness s_f is reached with an exactness of 3.0 ± 0.1 mm. In the same example, flange surfaces turned towards the supporting rolls demonstrate clearly identifiable grooves. The use of DD11 shows macroscopical cracks at a splitting depth of $y_{ges} = 30$ mm in the upper side. Up to now, on account of elastic compliances of the tool systems used, manufactured profiles show an enlargement of thickness in the web area.

The micro hardness measurements of a DD11 test body ($y_{ges} = 10$ mm) is based on micro structure sections in the y–z-plane. The basic hardness of the undeformed sheet metal (160 ± 20 HV) is retained in the web area. The micro hardness rises at most to ΔHV = 100%. This corresponds to a strain hardening in the contact area of the splitting roll radius. From here, a decrease of the micro hardness is visible in inner work piece areas, as well as in the flange end. This distribution shows an extensive qualitative correlation with the equivalent plastic strains that were calculated (Fig. 9).

The microscopic analysis proves that formed parts are free of cracks and with uninterrupted fiber course (Fig. 10). Concerning

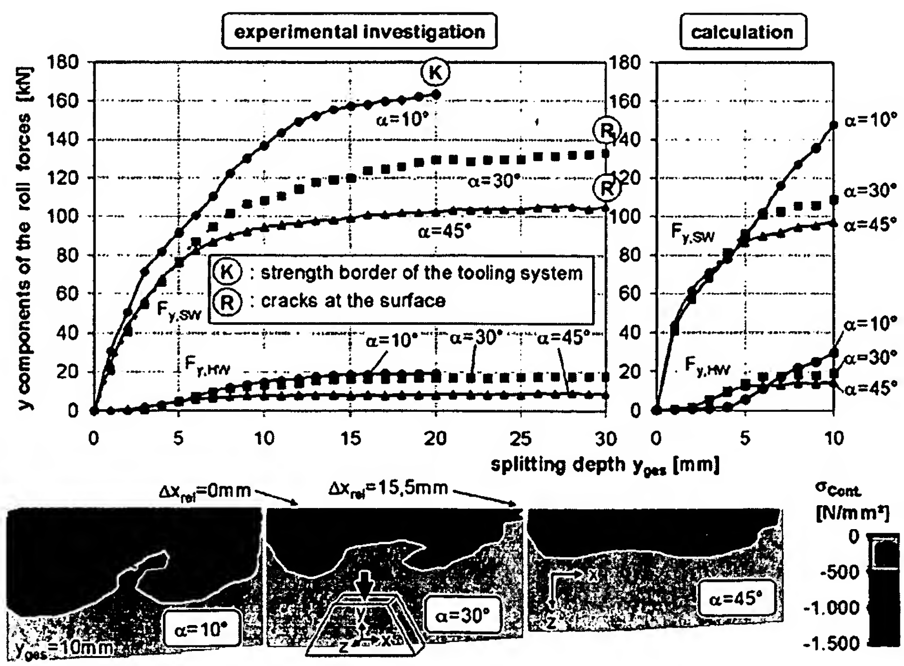


Fig. 12. Experimentally and numerically ascertained reaction forces (above), calculated contact normal stresses at the profile upper side ($R = 5$; $h = 5$; $s_0 = 6$; $s_f = 3$; $y_{int} = 1$ mm, DD11).

the DD11 material, metallographic micrographs of well-chosen work piece areas after the final splitting depth $y_{ges} = 10$ mm show the forming process' influence on the structure. In the radius zone of the splitting roll (1), large elongation of the metal grain can be observed in z-direction and compressions in y-direction. Those abate towards the internal profile center line and decrease with Δz_{rel} successively (2). The top, the lower side of the flange (3 and 4), as well as the contact area of the supporting rolls radii (5) demonstrate none or only slightly formed structures.

Specific failure cases of work pieces are classifiable in tearing and layer separation. They appear especially in the area of the radius and adjoining flange regions.

For the evaluation of the upper side topography, average surface finish R_a and medium/maximum surface roughness R_z and R_{max} will be considered. Work pieces with $y_{ges} = 20$ mm have much smoother flange surfaces than those with $y_{ges} = 10$ mm. However, further increase of the splitting depth only causes few changes. The use of DD11 with $y_{ges} = 20$ or 30 mm gives reproducible values for the average surface finish of $R_a \approx 0.1$–0.2 (Fig. 11).

6. Reaction force

Fig. 12 shows the influence of the splitting roll angle on reaction forces of the splitting roll and supporting rolls.

With decreasing flank angle, larger reaction forces originate in the rolls. This leads to a tool-sided inroad in the case of $\alpha = 10°$ with a final splitting depth of $y_{ges} = 20$ mm. In cases $\alpha = 30°$ or $45°$, macroscopic tearing appears at $y_{ges} = 30$ mm in the radius area of the upper side. The reaction force ($F_{y,}$ sw) calculated numerically shows at $y_{ges} = 10$ mm few differences in comparison to measured amounts. The relatively largest reaction force $F_{y,\mathrm{SW}}$ with $\alpha = 10°$ originates from the enlarged surface contact in z-direction. This is indicated by the contact normal stresses calculated at the profile upper side. The achieved final splitting depth y_{ges} is limited by the strength border of the tooling system and cracks at the upper side of the profile.

Experimental investigations with an offset of $\Delta x = 13.5$ mm show in comparison to no offset, a rise in the final splitting depth of more than 83% with the above described configuration but an incremental splitting depth of $y_{ink} = 0.5$ mm. Thus, an extension of the obtainable final splitting depth can be achieved by optimizing the stress state in the local forming zone.

7. Conclusions

The new forming process "linear flow splitting" offers the possibility to produce one-piece bifurcated profiles out of sheet metal. The determination of forming characteristics, forming velocity and stress states, as well as the underlying material flow is based on numerical calculations. Beside the verification of numerical results, experimental investigations deliver typical process limitations and failure cases. The extension of ascertained process limitations is at the center of future investigations.

Acknowledgements

The investigations presented in this paper were carried out within the research project "Spaltprofilieren von Dickblechen" GR 1818/7-2, supported by the German Research Foundation (DFG). The authors also thank the DFG for supporting future investigations within the subproject B1 of the Collaborative Research Center 666 "Integral sheet metal design with higher order bifurcations—Development, Production, Evaluation" (SFB666).

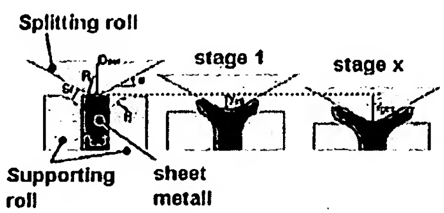
References

[1] W. Nachtigall, Bionik, Grundlagen und Beispiele für Ingenieure und Naturwissenschaftler, Springer, Berlin, Germany, 1998.
[2] M. Kleiner, M. Klaus, Manufacturing of lightweight components by metal forming, Ann. CIRP 52 (2) (2003).
[3] J. Wiedemann, Leichtbau, Band 1: Elemente, Band 2: Konstruktion, Springer-Verlag, Berlin, Germany, 1999.
[4] P. Groche, D. Vucic, M. Jöckel, Steifigkeitsoptimierter Leichtbau durch neue Umformverfahren für Blech, Tagungsband, MAT-INFO Werkstoff-Informationsgesellschaft mbH, Weinheim, Germany, 2004.
[5] S. Hauk, Grundlagen des Fließspaltens von Blechronden (Diss.), Shaker Verlag, Aachen, Germany, 1999.
[6] Autorenkollektion, 2003. DIN 8583- Fertigungsverfahren Druckumformen, Beuth, Germany.
[7] H. Stenger, Über die Abhängigkeit des Formänderungsvermögens metallischer Werkstoffe vom Spannungszustand: Dissertation am Institut für bildsame Formgebung der RWTH Aachen, Aachen, Germany, 1965.
[8] M. Jöckel, Grundlagen des Spaltprofilierens von Blechplatinen; Dissertation am Institut für Produktionstechnik und Umformmaschinen der TU Darmstadt, Shaker Verlag, Aachen, Germany, 2005.

APPENDIX B

Principle of Profiling Gaps

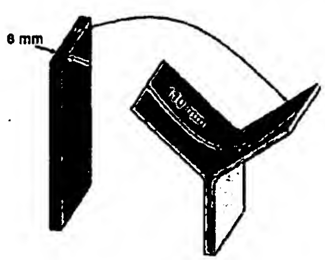
- double sided splitting rolls
- spanned supporting rolls

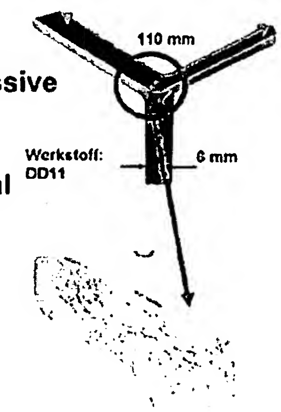


surface - enlargement caused by

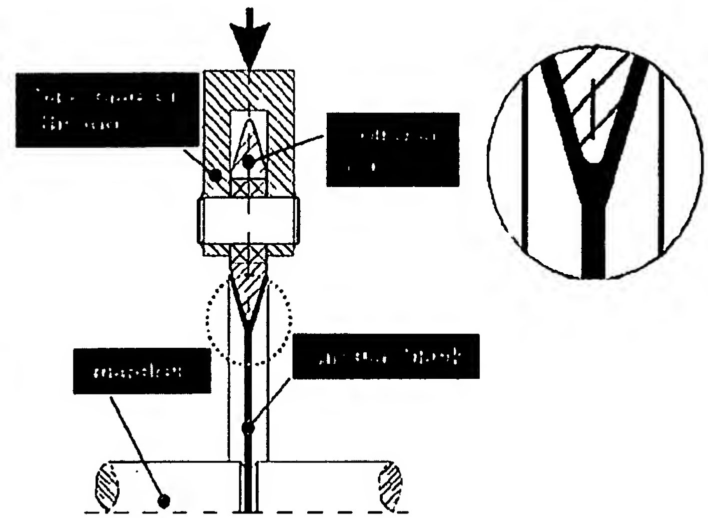
- specific tool-system
- initiation of a high hydrostatic compressive stress state into the forming zone

→ increased formability of the material
→ no cracks in the workpiece





Principle of Jelenak



issues:

- cracks in the workpiece
- positioning of the splitting roll and the circular blank
- not controllable material flow